Experimental Investigation and Heat Transfer Analysis of a Dimple Tube and Corrugated Tube Heat Exchanger

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Abstract— Heat transfer enhancement of dimple, corrugated and plain tube is done in this study. Here, voltage is varying from 60-100 v. There is wide increase in heat transfer from corrugated tube after 80 Volts. Hence, we have high heat transfer in the corrugated tube at higher voltages.

Keywords: Heat Transfer Analysis, Corrugated Tube Heat Exchanger, Dimple Tube

I. INTRODUCTION

A. *Modes of Heat Transfer*

1) Conduction
2) Convection
3) Radiation

B. *Heat Transfer by Convection*

There are certain situations in which the fluid motion is produced due to change in density resulting from temperature gradients, which is the heat transfer mechanism called as free or natural convection. Natural convection is the principal mode of heat transfer from pipes, refrigerating coils, hot radiators etc. The movement of fluid in free convection is due to the fact that the fluid particles in the immediate vicinity of the hot object become warmer than the surrounding fluid resulting in a local change of density. contrast to the forced convection, natural convection phenomenon is due to the temperature difference between the surface and the fluid is not created by any external agency. Natural convection flow pattern for some commonly observed situations is given in Figure 1.

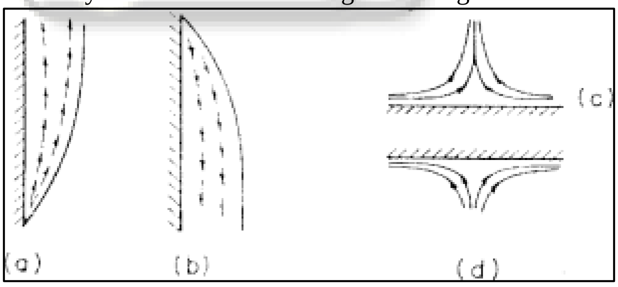


Fig. 1: Natural convection flow patterns

1) Heated vertical plate
2) Cooled vertical plate
3) Upper surface of a heated horizontal plate
4) Lower surface of a heated horizontal plate

Convection is the transfer of heat energy through a material by the bodily movement of particles and will occur in fluids (liquids and gases).Convection arises when a fluid is warmed, and thus expanded. The expanded fluid is less dense and therefore rises and is replaced by cooler fluid, which then undergoes the same process. This is called convection current. Convection can be natural or forced. Natural convection is when the fluid movement is caused by the fluid itself, whilst forced convection uses external means (such as a fan) to drive the fluid movement.

The rate of heat transfer due to convection is given by; $Q = h A(TS - T\alpha)$ Where;
h : is the convective heat transfer coefficient, in W/m^2K;
A : is the surface area, in m^2;
TS : is the surface temperature, in K;

$T\alpha$: is the fluid temperature, in K. h will depend upon; the relative velocity of the fluid; the temperature difference between the surface and the environment; the direction of heat flow; the surface size and orientation; the fluid properties (density, viscosity, heat capacity etc); Surface roughness.

The resistance of convective heat transfer is given by;
Where;
R_{conv} is the thermal resistance of convection, in m^2K/W. Therefore; $Q = (T_S - T_\alpha)/ R_{conv}$

To lower the heat flow due to convective heat transfer you can reduce the area in contact with the fluid, or decrease the convective heat transfer coefficient.

With the growing sophistication in technology and with the increasing concern with energy and the environment, the study of heat transfer has, over the past several years, been related to a very wide variety of problems, each with its own demands of precision and elaboration in the understanding of the particular processes of interest. Areas of study range from Atmospheric, geophysical and environmental problems to those in heat rejection, space research and manufacturing systems.

C. *Applications of Natural Convection*

Natural Convection flow encountered in several areas of applied engineering:

$$Nu = 0.36 + \frac{0.518 Ra^{1/4}}{\left[1 + (0.559/Pr)^{9/16}\right]^{4/9}}$$

$$Nu = \left\{0.60 + \frac{0.387 Ra^{1/6}}{\left[1 + (0.559/Pr)^{9/16}\right]^{8/27}}\right\}^2$$

1) Extended fins
2) Heat exchangers
3) Nuclear reactors
4) Solar heating systems
5) Dry cooling towers
6) Cooling of electronic equipments

Equations are developed to define the performance advantage of roughened tubes in heat exchanger design, relative to smooth tubes of equal diameter. Three rough tube applications are presented: 1. To obtain increased heat exchange capacity; 2. To reduce the friction power; and 3. To permit a reduction of heat-transfer surface area.

II. LITERATURE REVIEW

A. *Correlations for Natural Convection.*

There is lot of literature available on different topics of different modes of heat transfer. However, I have restricted the literature survey only to Natural Convection from surfaces.

- Some correlations for natural convection
- A physical discussion of natural convection along inclined and horizontal plates

1) Inclined and horizontal plates

Compared with vertical plates, inclined and horizontal plates have reduced fluid Velocities along the plate. One might expect that there is a reduction in convection heat transfer. Whether, in fact, there is such a reduction depends on whether one is looking at the top or bottom surface of the plate. On top of a cold inclined plate, the reduction of the gravity that acts in the direction parallel to the plate reduces the convection heat transfer. For the top of the cold plate and the bottom of the heated plate and $0^0 < \theta < 60^0$ the same Nusselt number correlations as for vertical plates can be used if g is replaced by g cos θ. For the opposite surfaces, literature should be consulted. For horizontal plates the following correlations are recommended for upper surface of heated plate or lower surface of cooled plate is,

$Nu=0.54\ Ra^{1/4}$ ($10^4 < Ra < 10^7$)

and for lower surface of heated plate or upper surface of cooled plate $Nu=0.27\ Ra^{1/3}$ ($10^7 < Ra < 10^{11}$)

2) The long horizontal cylinder

This geometry has been studied extensively and Incropera has a reference to a review. A correlation for a wide Rayleigh number range of an iso-thermal cylinder. The local Nusselt number is influenced by boundary layer development . The decay of local Nusselt number would be disrupted at Rayleigh numbers sufficiently large to permit transition to turbulence within the boundary layer.

3) Free convection within parallel plate channels

Vertical (or inclined) parallel plate channels that are open to the ambient at opposite ends are common in many applications. Surface thermal conditions may be idealized as being isothermal or isoflux and symmetrical (both walls have the same temperature or flux) or asymmetrical (different temperature or flux on the walls). For short channels and/or large plate spacing the boundary layers correspond to those for an isolated plate in an infinite, quiescent medium.

4) Rectangular enclosures

Some results are presented for rectangular cavities where two of the opposing walls are maintained at different temperatures, while the other walls are insulated from the surroundings. The cavity may be tilted from horizontal to vertical. The heat flux is expressed as,

$q_l = h(T_1 - T_2)$

As a first approximation, convection coefficients for the horizontal cavity heated from below may be obtained from the following correlation

$Nu = 0.069\ RaL^{1/3} Pr^{0.074}$ $3x10^5$ $RaL < 7x10^9$

where all fluid properties are evaluated at the average temperature,

$T = (T_1 + T_2)/2$. This correlation thus applies for Rayleigh numbers where the flow is turbulent. For vertical rectangular cavities with aspect ratios in the range $1 < H/L < 10$ (L is the distance between the hot and cold surfaces) the following correlations have been suggested.

For the largest aspect ratio correlations have been proposed $Nu_L = 0.42Ra^{1/4}$ Pr0.012 $(H/L)^{-0.3}$

$10 < H/L < 40$

$1 < Pr < 2.10^4$

$10^4 < Ra < 10^7$ $Nu = 0.046Ra^{1/3}$ $1 < H/L < 40$

$1 < Pr < 20$

$10^6 < Ra < 10^9$

1) The pioneering work on the problem of natural convention in vertical plates is traced back by W. Elenbass [2] (1942) who analyzed the laminar natural convection heat transfer in a smooth parallel plate vertical channels without internal bodies & a detailed study of the thermal characteristics of cooling by natural convection was reported. This work was followed by many experimental, theoretical & numerical investigations for both laminar & turbulent flow regimes. Only the configuration of natural convection in vertical channel with internal objects will be reviewed here.
2) I.H.Toruka [3] performed experimental study free convection from a cylinder array arranged in a vertical line between parallel walls.
3) Y.Shen, P.Tong[4][1998], explained light scattering experiment of turbulent convection in water is carried out in a convection cell with rough upper and lower surfaces.
4) Y.B. Du[5](1998), performed novel convection experiment is in a cell with rough upper and lower surfaces.
5) N.Onur and M.K.Akta[6] performed study on natural convection between inclined plates. The plate inclinations were chosen to be 0^0,30^0,45^0 and measured with respect to vertical position.
6) Ademola A. Dare and Moses O. Petinrin[7](2010) explained diffusion velocity method (DVM), a version of vortex element method(VEM), was used to model the steady state, laminar natural convection flows along isothermal vertical plates and in isothermal vertical channels.
7) A.M.Clausing Professor, Mem. ASME[8](1989),his investigation on natural convection from a heated, upward facing, square, horizontal to surrounding gas medium is described.
8) S.M.Guo,C.C.Lai[9](2000) studied influence of surface roughness on heat transfer coefficient and cooling effectiveness for a fully film cooled three dimensional nozzle guide vane(NGV) has been measured in a transonic annular cascade using wide band liquid crystal and direct heat flux gases(DHFG).
9) Rossano Comunelo[10](2005),his work deals with heat transfer coefficient ―h‖ of a isothermal vertical plate with H = 0.15 m. The neighborhood surfaces influence in that coefficient is aimed with simulation and standard experimentation.
10) J.W. Zhou , Y.G. Wang [11](2008) studies that determine the influence of unsteadiness on flat plate impinging jet heat transfer implicitly assume that the effect of unsteadiness found on smooth impingement surfaces also holds on surfaces with certain obstacles on them.

11) P.Kandaswamy, J. Lee, A.K.Abdul Hakeem [12](2007) studies Natural convection heat transfer in a square cavity induced by heated plate numerically. Top and bottom of the cavity are adiabatic, the two vertical walls of the cavity have constant temperature lower than the plate's temperature.
12) A.A.Walunj, D.D.Palande [13]((2014) studies Steady state natural convection from heat sink with narrow plate-fins having parallel arrangement mounted on inclined base was experimentally investigated.

III. DESIGN METHODOLOGY AND FABRICATION

A. *Components and description*

– Enclosure- .Square pyramid
– Tubes- a. Plain Cylindrical Brass tube

B. *Corrugated Brass tube*

C. *Brass tube with Dimples*

– Band type heater
– Thermocouples
– Ammeter
– Voltmeter
– Dimmerstat
– Temperature indicator
– Toggle switches
– Stand

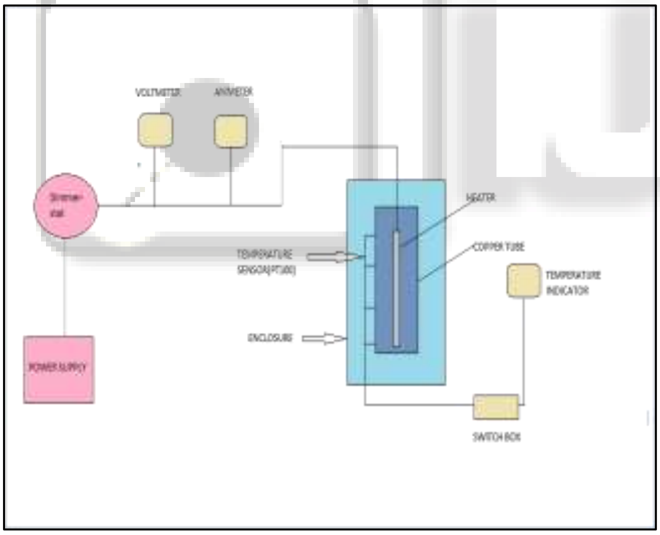


Fig. 2: line diagram of experimental setup

1) *Enclosure:*

Square Pyramid type enclosure is used. From mild steel sheet we fabricated enclosure. Natural convection in enclosures has attracted considerable interest of investigators as the transport process in a fluid where the motion derives by the interaction of a difference in density with a gravitational field is very common in several engineering and environmental problems.

2) *Tubes*

There are three types of tubes used in this experiment the simple tube, corrugated tube and tube with dimples.The material used for tubes is Brass. Heat transfer rate for simple tube is calculated using the setup. Heat transfer rate of simple tube is compared with heat transfer rate of corrugated and dimpled tube.

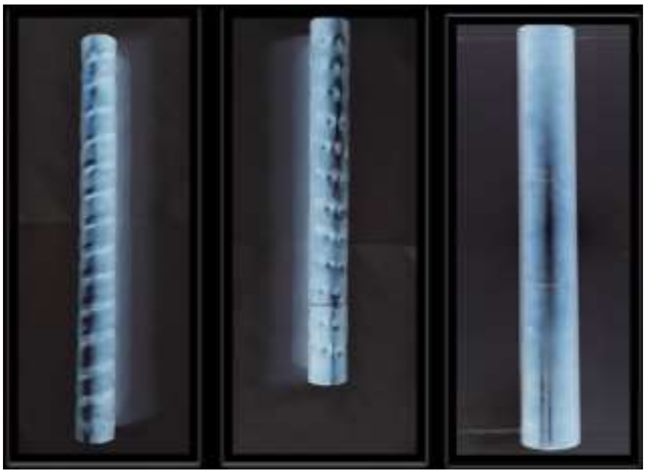


Fig. 3:

3) *Cartridge Heater:*

Industrial heaters can made with NEMA 1 terminal boxes or NEMA4 moisture resistant terminal boxes that protect terminations and have the option of a thermostat thermocouple digital temperature controller to help control and regulate applied heat.

Specifications of band type heater: Resistance- +10%-5% Wattage:+5%-10%

watt density-8W/sq.cm Voltage:100V to 200V AC Max Temperature:200 °C Diameter:9mm.

4) *Thermocouples:*

We have used PT-100 type temperature sensors in order to sense tube temperature.

4 temperature sensors are arranged on tube surface and one sensor senses the atmospheric temperature.

The PT-100 provides excellent accuracy over a wide temperature range. Standard sensors are available from many manufacturers with numerous accuracy specifications and numerous packing options to suit most applications. The principle of operation is to measure the resistance of platinum element. The PT-100 has a resistance of 100 ohms at 0 °C.

5) *AMMETER:*

Early ammeters were laboratory instruments which relied on the Earth's magnetic field for operation.
Specifications:

EasyLogic DM3000 / DM1000 Single Phase Ammeter Accuracy Class 0.5

Input Voltage measurement range 80-480V AC (L-L) Flush mounting 92 x 92mm
CT/PT site programmable
Typically used for measure Current (A) in Panel boards

6) *VOLTMETER:*

Digital meters can be made with high accuracy, typically better than 1%.

EasyLogic DM3000 / DM1000 Single Phase Voltmeter
Accuracy Class 0.5

Input Voltage measurement range 80-480V AC (L-L) Flush mounting 92 x 92mm CT/PT site programmable Display: LED Display Accuracy Class: 0.5, 0.2, 1
Input Range: 80-480V AC (L-L) Standards: IEC 62053 21/22

7) IMMERSTAT-

Dimmerstat is used to adjust the output potential/voltage to an electrical circuits. Access Variac Dimmerstat Auto Transformer is Flush Open Type 1phase 0 to 270V AC 1A Mounted in Your Cabinet Instrument, crafted with excellence.

8) TOGGLE SWITCH-

A toggle switch is a class of electrical switches that are manually actuated by a mechanical lever, handle, or rocking mechanism. Toggle switches are available in many different styles and sizes, and are used in numerous applications.

9) STAND:

in this experimental setup stand or bed houses the complete electronic and mechanical components.the material used for stand is mil steel.dimensions include : 2 feet length, 2feet width ,2 feet height.

IV. METHODOLOGY:

The apparatus consists of a Brass tube fitted in a rectangular vertical duct. The duct is open at the top and bottom and forms an enclosure and serves the purpose of undisturbed surrounding. An electric heating element is kept in the vertical tube which in turn heats the tube surface. The heat is lost from the tube to the surrounding air by natural convection. The temperature of the vertical tube is measured by four thermocouples. The heat input to the heater is measured by an ammeter and a voltmeter and is varied by a dimmerstat. The tube surface is polished to minimize the radiation losses.

V. EXPERIMENTATION AND ANALYSIS

1) O.D. Cylinder = 38 mm.
2) Length of Cylinder = 400 mm.
3) Input to heater = V x I Watts.

A. *Observation table:*

SR.NO	Volt	Amp	Temperature °C				
			T1	T2	T3	T4	Ta
1	0	0	22.9	24.8	22.5	24.3	23
2	60	0.621	85.3	84.7	79.5	73.6	23.1
3	80	0.834	114.7	117.2	102	90.4	24.7
4	100	1.045	149.3	144.4	124.7	104.5	25.3

Table 1: For Simple Tube

SR.NO	Volt	Amp	Temperature °C				
			T1	T2	T3	T4	Ta
1	0	0	23.8	24.2	24.3	24.6	23
2	60	0.628	81.8	78.1	75.1	71.8	23
3	80	0.892	87.9	84.8	83.9	82.1	24.9
4	100	1.094	113.8	105.9	94.3	71.3	25.8

Table 2: For corrugated tube

SR.NO	Volt	Amp	Temperature °C				
			T1	T2	T3	T4	Ta
1	0	0	23.5	23.4	23.8	22.1	23
2	60	0.632	76	73.8	71.5	64.9	23
3	80	0.845	105.2	95.1	91.78	98.35	25
4	100	1.061	124.9	129.3	117.8	115.1	26

Table 3: For Tubes with dimples

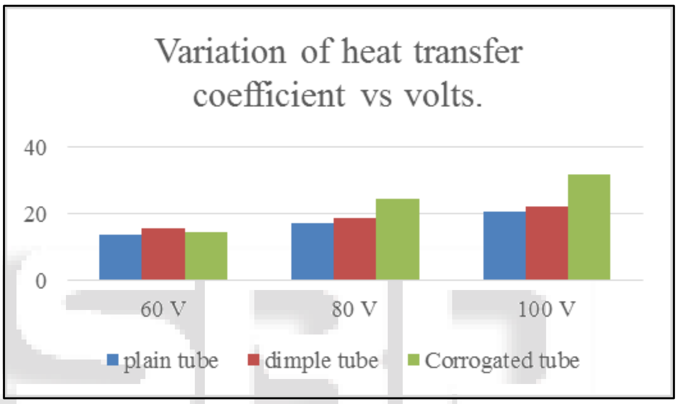
VI. RESULT ANALYSIS

Voltage	Plain tube Heat transfer coefficient ($W/m^2\,^{\circ}C$)	Dimpled tube Heat transfer coefficient ($W/m^2\,^{\circ}C$)	Corrugated tube Heat transfer coefficient ($W/m^2\,^{\circ}C$)
60	13.52894	15.6523	14.39335
80	17.17013	18.65798	24.48841
100	20. 75779	22.2005	31. 81996

Table 4:

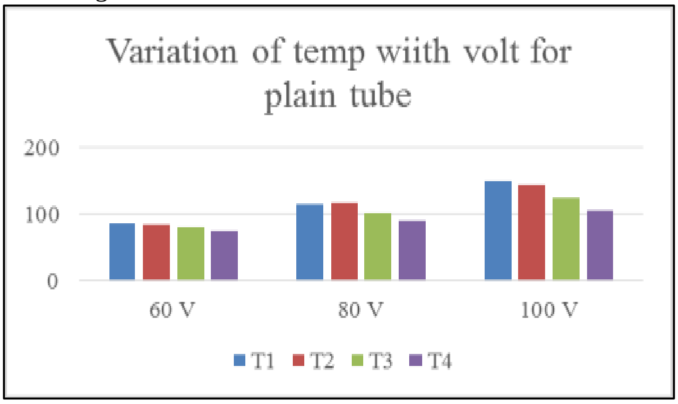
It is evident from above result that heat transfer coefficient for corrugated tube is highest. As we go on increasing the voltage the heat transfer rate goes on increasing but there is wide increase in heat transfer in corrugated tube after 80 volts.so hence we can have high heat transfer if we use corrugated tube and at higher voltages.

Following Graphs is reflects the brief Idea about Variation of various Parameter:



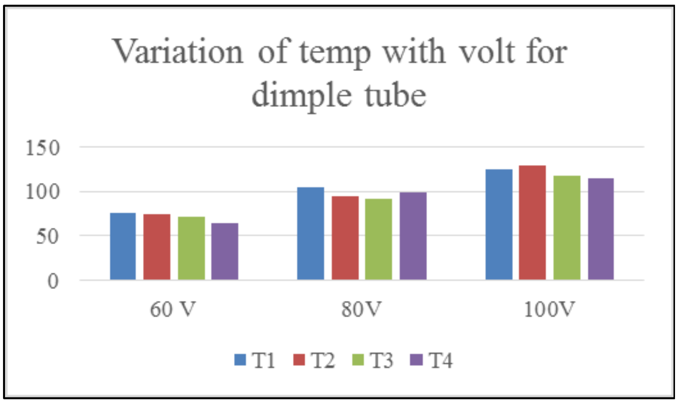
Graph 1:

From this graph it is observed that as the voltage incraeses the temperature is also incraeses and it is higher for corrugated tube at 100 Volt.



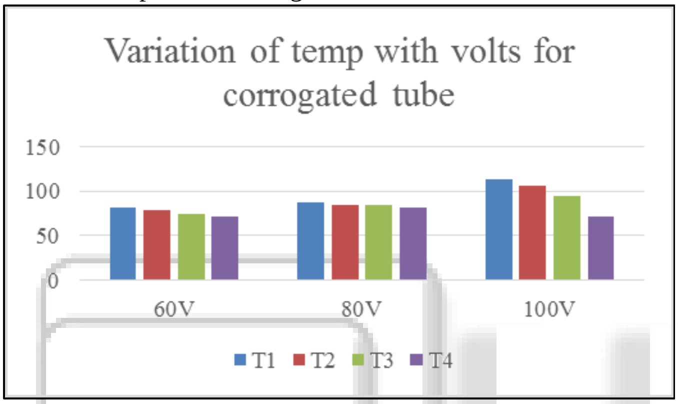
Graph 2:

Variation of temp with volt for plain tube temp T1 is higher in all the voltages because the position of the temperature sensor is nearer to the heater.



Graph 3:

Variation of temperature with volts for dimple tube temperature T_1 is higher at 60 and 80 V for all the tubes but at 100 V temperature T_2 is greater than T_1.



Graph 4:

Variation of temperature with volts for corrugated tube, here also the temperature T1 is greater for all the voltages for all the tubes and at 100 V the value of T4 is very less.

VII. Conclusion

Heat transfer enhancement of dimple, corrugated and plain tube is done in this study. Here, voltage is varying from 60-100 v. From the experiment outcomes we can conclude that the heat transfer is more from the corrugated tube as compared to dimple and plain tube, this is because of material peoerty and small reduction in the area as compared to dimple tube. It is seen that there is wide increase in heat transfer from corrugated tube after 80 Volts. Hence, we have high heat transfer in the corrugated tube at higher voltages.

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